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Effects of age on inhibitory control are affected by task-specific features

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Abstract

Older adults have been argued to have impoverished inhibitory control compared to younger adults. However, these effects of age may depend on processing speed and their manifestation may furthermore depend on the type of inhibitory control task that is used. We present two experiments that examine age effects on inhibition across three tasks: a Simon arrow, static flanker, and motion flanker task. The results showed overall slower RTs for older adults on all three tasks. However, effects of age on inhibition costs were only found for the Simon task, but not for the two flanker tasks. The motion flanker task furthermore showed an effect of baseline processing speed on the relation between age and inhibition costs. Older adults with slower baseline responses showed smaller inhibition costs, suggesting they were affected less by the flanker items than faster older adults. These findings suggest that effects of age on inhibition are task dependent and can be modulated by task-specific features such as the type of interference, type of stimuli, and processing speed.

Keywords: Cognitive ageing, inhibition, Simon task, flanker task

Word count: 10.405

1. Introduction

Older adults often have been found to have decreased cognitive abilities. An inhibition impairment has been suggested to underlie these age-related deficits in attentional and working memory tasks (e.g., Hasher & Zacks, 1998). However, the effects of age on inhibition have been questioned and may evaporate when correcting for general age-related slowing. Here, we present two experiments that investigate the relationship between inhibition, age, and processing speed across three tasks.

Effects of age on inhibition have been studied across a wide range of tasks, including anti-saccade, go/no-go, and stop-signal tasks. Concerning interference suppression (i.e., the ability to suppress task-irrelevant information), the Simon and flanker tasks are two frequently used tasks. Apart from studying age effects, these tasks have also been used to examine effects of other variables such as bilingualism (e.g., Paap & Greenberg, 2013) and with clinical populations (e.g., Mullane, Corkum, Klein, & McLaughlin, 2009). In a Simon task, participants are typically presented with stimuli shown on the left or right side of the screen. Participants are instructed to press the left key for one stimulus and the right key for the other. Thus, the presentation side and response side can match (congruent) or mismatch (incongruent trials). Reaction times (RTs) are commonly faster for congruent than incongruent trials (Simon effect), which is taken as a measurement of inhibition. Older adults not only show longer overall RTs, but also have larger Simon costs than younger adults (e.g., Castel, Balota, Hutchison, Logan, & Yap, 2007; Proctor, Pick, Vu, & Anderson, 2005; Van der Lubbe & Verleger, 2002). These effects of age on the Simon effect remain when corrected for general processing speed differences, implying that the effects of age on inhibition go beyond general age-related slowing.

Similarly, in flanker tasks, the RT difference between congruent and incongruent trials is dubbed the *flanker effect*. In a commonly used version, the flanker arrow task, participants need to respond to a central arrow that is surrounded by flanker arrows pointing in the same or opposite direction. The flanker effect has been observed to be smaller for young than older adults (e.g., Colcombe, Kramer, Erickson, & Scalf, 2005; Shaw, 1991; Zeef & Kok, 1993; Zeef, Sonke, Kok, Buiten, & Kenemans, 1996; Zhou, Fan, Lee, Wang, & Wang, 2011; Zhu, Zacks, & Slade, 2010). Although not all of these studies presented analyses correcting for overall RT differences (e.g., Zeef & Kok, 1993; Zeef, 1996), those which did (e.g., Colcombe et al., 2005; Zhou et al., 2011), observed age effects on corrected flanker costs too.

In both Simon and flanker tasks, conflict can arise at the perceptual and/or motor level. At the level of motor responses, the conflict between stimulus and response (S-R) mappings in the Simon task and the conflict between flanker and target arrows in the flanker task requires inhibition of the incorrect response and hinders selection of the correct response. This conflict of S-R mappings takes place at a relatively late stage of processing, namely when motor responses need to be selected and prepared (e.g., Castel et al., 2007). However, the earlier stage of perceptual conflict too has been suggested to be the underlying source of inhibition costs in both younger (Van't Ent, 2002) and older adults (Hsieh, Liang, & Tsai, 2012). Motor and perceptual inhibition as well as the interplay between the two may furthermore be affected differently by age. When asked to complete an adaptation of the Simon task, older adults showed impairments on the motor and perceptual inhibition tasks separately compared to younger adults. On the task that required both perceptual and motor inhibition, older adults showed an interaction between perceptual and motor conflict, suggesting that the two types of inhibitory processes are not independent but may share cognitive resources. In contrast, this interaction was not observed for younger adults, which has been interpreted as perceptual and motor conflict reflecting two distinct processes in the younger age group (Germain & Collette, 2008; see Naussauer & Halperin, 2003, for similar findings with younger adults).

Yet, the finding that older adults have diminished inhibitory control has been challenged, especially on flanker tasks. Several studies have observed overall RT effects of age but no age group difference on flanker costs (e.g., Collette, Schmidt, Scherrer, Adam, & Salmon, 2009; Fernandez-Duque & Black, 2006; Gamboz, Zamarian, & Cavallero, 2010; Hsieh & Fang, 2012; Jennings et al., 2007; Wild-Wall, Falkenstein, and Hohnsbein, 2008) or even small advantages for older adults (e.g., Hsieh et al., 2012; Mathewson, Dywan, Segalowitz, 2005). In some of these studies, effects of age were found on raw inhibition costs, but not on costs corrected for age-related slowing (e.g., Jennings et al., 2007). Indeed, in a meta-analysis of ageing studies using a wide range of executive control tasks (including the flanker task), Verhaeghen (2011) concludes that most tasks did not show ageing effects beyond the effects already observed in baseline conditions without conflict. This suggests that older adults may perform slower overall on a flanker task but do not have an inhibition deficit in particular. An EEG study by Wild-Wall et al. (2008) also implied that processing speed may matter on the flanker task. Their data suggested that older adults focus more on the target, are less affected by the flankers, and need more time for stimulus transmission from visual to motor areas. Older adults needing more time at the perceptual stage to process flanker items and consequently being hindered less by those flankers could explain why inhibition deficits for older adults are not observed on flanker tasks.

Examining findings across different studies in the literature suggests that effects of age on inhibition tasks are more likely to be found in Simon than flanker paradigms. Yet, only a few studies have compared age effects on Simon and flanker paradigms within one study. Kawai, Kubo-Kawai, Kubo, Terazawa, and Masataka (2012) form an exception as they compared younger and older adults completing a Simon arrow and flanker task. While older adults showed larger Simon costs than younger adults, there was no difference in flanker costs between the two groups. Similarly, using other task paradigms, studies have observed age effects on some inhibition tasks including Stroop and response stopping tasks but not on others such as negative priming paradigms (e.g., Andrés, Guerrini, Phillips, & Perfect, 2008; Kramer, Humphrey, Larish, Logan, & Strayer, 1994). These results suggest that age effects on inhibitory control may be task-specific.

Furthermore, not only effects of age but also the conflict costs themselves have been found to differ between different types of inhibition tasks. For instance, when Simon and flanker effects were compared, Paap and Greenberg (2013) only observed a correlation of r = -.01. Moreover, Shilling, Chetwynd, and Rabbitt (2002) obtained a high correlation between two almost identical versions of a Stroop task while only very weak correlations were found on four different measures of the Stroop effect. These low correlations between tasks highlight the influence of task-specific features when measuring inhibitory control across task versions (also referred to as ´task impurity´).

We therefore investigated effects of age on inhibition across three different inhibitory control tasks. Furthermore, as the speed with which perceptual information is processed has been suggested to affect inhibition costs and age effects (e.g., Wild-Wall et al., 2008), we further investigated the possible relationship between perceptual processing speed, age, and inhibition. Following Kawai et al. (2012) and considering the frequency with which these tasks have been used to assess interference suppression in general or in specific populations, we examined performance between younger and older adults on Simon arrow and flanker tasks.

In Experiment 1, we firstly present a novel motion flanker task that is similar to a static flanker task and has shown similar flanker costs when used with younger adults (Lange-Malecki & Treue, 2012). As motion perception generally deteriorates with age (e.g., Billino, Bremmer, & Gegenfurtner, 2008; Tran, Silverman, Zimmerman, & Feldon, 1998), we used this motion flanker task aiming to elicit more variability in baseline processing speed in order to study the link with inhibition costs. However, as age effects may be modified by task-specific features, Experiment 2 compares effects of age and speed across three different inhibition tasks (Simon arrow, static flanker, and motion flanker tasks).

2. Experiment 1

In Experiment 1, older and younger adults completed a motion flanker task. If older adults indeed perceive motion more slowly than younger adults, flanker items should cause less interference, and thus flanker costs should be similar for the two age groups or even smaller for older adults. Furthermore, if slower motion perception leads to less interference, we hypothesised that older adults with faster motion perception should show larger flanker costs than slower adults.

Using moving instead of static stimuli also allowed us to manipulate the percentage of conflict by changing the motion coherency of flanker dots. For example, in a low coherency condition, a small percentage of flanker dots would move in a congruent or incongruent manner with the other dots moving randomly. In a high coherency condition, all flanker dots would move (in)congruently, thus leading to more conflict. In this way, we examined whether age groups were affected differently by the amount of conflict.

Experiment 1 thus had two main aims. Firstly, we wanted to examine effects of age, congruency, and coherency (i.e., conflict level) on a motion flanker task. Secondly, we aimed to investigate whether baseline processing speed affected inhibition costs in younger and older adults.

2.1. Methods

2.1.1. Participants

Twenty younger adults (9 male; mean age = 21.45, *SD* = 2.84, range = 18-27) and 20 older adults (9 male; mean age = 66.35, *SD* = 3.92, range = 60-74) participated in Experiment 1[1]. All

[1] Effects of age on a motion flanker task have not been studied before. The participant sample for Experiment 1 is therefore based on previous studies using a static flanker task. Zhou et al. (2011) showed a significant effect

participants had normal or corrected-to-normal vision and hearing, no known neurological disorders, and gave written informed consents. All participants were monolingual English native speakers living in the United Kingdom. Younger and older adults did not differ in years of education (young: M = 15.60, SD = 1.85; old: M = 16.45, SD = 2.67; $t(38) = 1.17$, $p = .248$). Furthermore, scores on an 18-item lifestyle questionnaire (Scarmeas et al., 2003, maximum score = 54) were similar for young (M = 39.85, SD = 3.13) and older adults (M = 41.55, SD = 4.98; $t(38) = 1.29$, $p = .204$). Older adults also completed the ACE-III as a dementia screening (Hsieh, Schubert, Hoon, Mioshi, & Hodges, 2013) and all scored above the cut-off of 88 points (M = 97.85, SD = 2.37).

2.1.2. Materials and procedure

Participants completed a motion flanker task in which they saw groups of dots moving to the left or right and were asked to indicate motion direction with a button press. In the baseline condition, participants saw one group of dots on the centre of the screen with all dots moving left or right. In the conflict condition, this central group of dots was surrounded by two other groups of dots that moved randomly (neutral condition), in the same (congruent), or opposite (incongruent) direction. Participants were asked to respond to the central group of dots. The motion coherency of the flanker dots was manipulated, thus leading to different conflict levels (40%, 60%, 80%, or 100% coherent movement). For instance, in a 60% incongruent condition, 60% of the flanker dots would move in the opposite direction than the target dots (see Figure 1). The other 40% of the flanker dots would move in a random direction. The difference between incongruent and congruent trials was defined as the flanker effect.

Each trial started with a fixation cross on the centre of the screen for 500 ms. Then, the flankers and central dots were presented for 3000 ms or until a response was given. Following Lange-Malecki and Treue (2012), the flanker dots were presented 100 ms prior to the presentation of the central target.

Participants first completed a practice block for the baseline condition, containing a minimum of 8 trials. Practice continued until an accuracy level of 80% was reached. During the practice block, participants received feedback about their performance. This was followed by

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of age on conflict costs in a static flanker task with d = 1.12 (calculated from the young – old comparison, excluding the middle-aged group). Based on this effect size, 14 participants per group would yield > 80% power to detect a significant effect of age.

a baseline block of 30 trials. Participants then completed a practice block for the conflict condition with a minimum of 24 trials. The conflict condition consisted of a total of 300 trials divided over four blocks. Sixty trials were neutral trials in which the flanker dots moved randomly. Of the 240 conflict trials, 120 were incongruent and 120 congruent. Congruency (incongruent or congruent), motion direction (left or right), and coherency (40%, 60%, 80%, 100%) were distributed evenly across trials.

The task was presented in PsychoPy v 1.82 (Peirce, 2007) and moving dots were generated through the DotStim package. Each group of dots consisted of 80 dots presented within a circle. The dot size was two pixels, the life of each dot was 8 frames, and the speed .09 pixels per frame. The size of the group of dots was 100 pixels. The randomly moving dots followed a random but constant direction, while the coherent dots moved right or left. The black dots were presented on a grey background on a 19-inch screen with 1280x1024 resolution. The complete experiment lasted approximately 30 minutes for younger adults and 45 minutes for older adults.

[Insert Figure 1 about here]

2.1.3. Data analysis

The data are available upon request. We analysed the RT data using both null hypothesis statistical testing (NHST) as well as Bayesian analysis. The Bayes factor (BF) states the probability of the data given the alternative hypothesis over the probability of the data given the null hypothesis. For instance, when $BF_{10} = 3$, the observed data are three times more likely to have occurred under the alternative than null hypothesis. Conversely, $BF_{10} = 0.33$ means that the data were three times more likely to have occurred under the null hypothesis. We used the Bayes Factor package in R (Morey & Rouder, 2011), with the default prior $r = .707$ (Rouder, Morey, Speckman, & Province, 2012), and one million iterations to calculate the Bayes factors. We only provide Bayes Factors for the variables of interest (i.e., age in relation to trial type/congruency and baseline processing speed). For the corresponding ANOVA analyses, these are presented as a contrast between models with and without the factor of interest (e.g., comparing a model with the main effects of age and congruency as well as the age x congruency interaction to a model with the main effects of age and congruency only).

We were furthermore interested in examining the relation between how quickly adults process the stimuli in the absence of conflict (baseline processing speed) and the actual conflict cost. As a measure of this baseline processing speed, we used the RTs from the baseline condition in which participants responded to the presentation of one central group of moving dots in the absence of conflict. We then ran a regression with age and baseline processing speed RTs as predictors and flanker costs as the dependent variable.

Lastly, in order to study inhibition and the possible effects of age in more detail, we conducted a delta-plot analysis (cf., Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004). Inhibition is argued to require time to build up and may thus be more effective as time increases. Delta plots present the conflict effect (e.g., flanker cost) as a function of overall response time on the conflict task. Thus, if time is needed to apply inhibition, smaller inhibition costs are expected for slower RTs (visible as a negative slope in the delta plot). Furthermore, this decrease is expected to be larger for adults with better inhibition compared to poor inhibition and for experimental conditions that require more inhibition compared to conditions with lower demands. Indeed, Ridderinkhof et al. (2004) showed that participants with lower Simon costs showed a reduction in conflict costs as RTs increased, while participants with higher Simon costs showed larger conflict costs for slower RTs. Furthermore, on a Simon task, young adults (19 – 26 years) showed decreasing conflict costs, while older adults (60 – 69 years old) showed similar costs or increasing costs (in the 70 – 82 age group) for increasing RTs (Juncos-Rabadán, Pereiro, & Facal, 2008). Similarly on the flanker task, when clinical populations with diminished inhibitory control were compared to healthy older adults, the former group showed a larger increase of flanker costs with increasing RT (Wylie, Ridderinkhof, Eckerle, & Manning, 2007).

For the delta-plot analysis, tertiles (33.33% bins) were created for each participant for the congruent and incongruent condition for low (40% + 60%) and high coherency levels (80% + 100%). We regrouped the four coherency levels into two levels to have more trials per tertile. Per bin, the average RT (AvQ) was calculated across incongruent and congruent conditions. Furthermore, the delta (D; difference between incongruent and congruent) was calculated per bin. Then, the slopes between each bin were calculated (e.g., (D2-D1)/(AvQ2-AvQ1). We analysed effects of coherency level and age on the slopes.

2.2. Results

2.2.1. Accuracy analysis

Accuracy data were analysed using a binary logistic regression analysis. On the baseline condition, there was no effect of age on accuracy ($\chi^2(1) = .14$ $p = .706$; young: *M* = 99.33, *SD* = 7.06; older: *M* = 99.50, *SD* = 8.14). On the conflict condition (see Table 1), there was no effect of age ($\chi^2(1) = 3.44$, $p = .064$). Incongruent trials were furthermore less accurate than congruent trials ($\chi^2(1) = 5.86$, $p = .015$) but no effect of coherency ($\chi^2(3) = 6.59$, $p = .086$) was observed. None of the interactions were significant ($p > .05$).

2.2.2. RT analysis

Effects of age, coherency, and congruency

Incorrect trials and RTs more than 2.5 *SD* above the mean (2.14% of the correct trials) were removed for the RT analysis.

In the baseline condition, older adults (*M* = 732.11, *SD* = 251.82) responded more slowly than young adults (*M* = 550.51, *SD* = 295.93; $t(38) = 2.09$, $p = .043$, $\eta_p^2 = .10$, $BF_{10} = 1.67 \pm 0$).

For the conflict condition, we carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. There was a main effect of trial type ($F(2, 76) = 15.72$, MSE = 427.04, $p < .001$, $\eta_p^2 = .29$). While RTs were similar for congruent trials (*M* = 601.81, *SD* = 186.28) and neutral trials (*M* = 593.40, *SD* = 180.61), they were slower for incongruent trials (*M* = 618.83, *SD* = 180.56). Older adults (*M* = 701.50, *SD* = 170.12) performed more slowly than younger adults overall (*M* = 512.12, *SD* = 142.24; $F(1, 38) = 14.45$, MSE = 73666.75, $p = .001$, $\eta_p^2 = .28$). The interaction between age and trial type was not significant ($F(2, 76) = 1.00$, MSE = 427.04, $p = .374$, $\eta_p^2 = .03$). This suggests that flanker effects did not differ between age groups (see Table 1). This was confirmed by the Bayesian analysis. Comparing the model with the interaction age x trial type to the model with the main effects age and trial type only, showed that the model without the interaction fits the data better by a factor of 3.55 (± 2.40%).

We then examined the effects of coherency level by only including congruent and incongruent trials in a three-way repeated ANOVA with trial type (congruent, incongruent) and coherency level (40%, 60%, 80%, 100%) as within-subject factors and age group (young, old) as a between-subject factor. Similar to the previous analysis, the main effects of congruency ($F(1, 38) = 10.76$, $p = .002$, MSE = 2155.44, $\eta_p^2 = .22$) and age ($F(1, 38) = 14.79$, MSE = 197407.61, $p < .001$, $\eta_p^2 = .28$) remained significant. The effect of coherency was significant ($F(3, 114) = 15.56$, MSE = 589.06, $p < .001$, $\eta_p^2 = .29$), with RTs increasing for higher coherency levels. The interaction between coherency and congruent was also significant, ($F(3, 114) = 4.38$, MSE = 463.40, $p = .006$, $\eta_p^2 = .10$), suggesting that flanker costs increased as coherency level increased (see Table 1). There was no interaction between age and congruency ($F(1, 38) = .77$, MSE = 2155.44, $p = .386$, $\eta_p^2 = .02$), age and coherency ($F(3, 114) = .46$, MSE = 589.06, $p = .712$, $\eta_p^2 = .01$), nor a three-way interaction ($F(3, 114) = .87$, MSE = 403.78, $p = .458$, $\eta_p^2 = .02$). The Bayesian analysis showed that a model with only the main effects of age and congruency was preferred compared to a model with the main effects and an interaction between age and congruency by a factor of 2.45 (± 1.16%).

To correct for overall RT differences, we also calculated proportional flanker costs (incongruent – congruent / congruent trials)[2] for the 100% coherency level. There was no significant effect of age on proportional inhibition costs ($t(38) = 1.18$, $p = .246$; $BF_{10} = .54 \pm 0\%$).

[Insert Table 1 about here]

Effects of baseline RTs on flanker costs

As a second question, we examined effects of baseline RTs on the flanker cost. To ensure comparisons with the static tasks in Experiment 2, we calculated flanker costs for the 100% coherency only (see Table 1). Using the 100% flanker costs as the dependent variable, we then ran a regression with age (young, old) and RTs from the baseline condition as predictors. This model suggested that while baseline ($b = .001$, $t = 1.29$, $p = .206$) was not a significant predictor, the interaction between baseline and age was ($b = -.005$, $t = -3.05$, $p = .004$). This suggests that the baseline RTs may have different effects for the two different age groups and we therefore analysed the two age groups separately. For the young adults, baseline RTs were a significant and positive predictor of flanker costs ($b = .06$, $t = 3.13$, $p = .006$, $BF_{10} = 7.71 \pm 0$). Thus, younger adults with faster baseline RTs also showed smaller flanker costs. For older

[2] Different techniques have been proposed to correct for overall RT slowing. While it has been argued that z-score transformations or regression analyses are preferable over proportional costs (e.g., Faust, Balota, Spieler, & Ferraro, 1999), several earlier ageing studies have used proportional or ratio analyses (e.g., Colcombe et al., 2005). We therefore provide the proportional cost analysis here while examining effects of RTs in more detail in the regression analysis.

adults, the effects of baseline RTs went in the opposite direction, with faster baseline RTs associated with larger flanker costs (b = -.12, t = -2.27, p = .036, BF_{10} = 2.12 ± 0).

2.2.3. Delta-plot analysis

The delta-plot analysis showed a main effect of coherency as the slopes were more negative for high coherency levels than low coherency levels ($F(1, 38) = 4.79$, MSE = .11, $p = .035$, $\eta_p^2 = .11$). This suggests that more inhibition was needed for conditions with higher coherency levels. Furthermore, slopes did not differ between younger and older adults (see Figure 2; $F(1, 38) = .63$, MSE = .11, $p = .432$, $\eta_p^2 = .02$), suggesting that both age groups used similar levels of inhibition. There was no main effect of bin ($F(1, 38) = 3.06$, MSE = .69, $p = .088$, $\eta_p^2 = .07$). None of the interactions were significant (all ps < .05). The Bayesian analysis showed that the model without age as a main effect fits the data better by a factor of 4.74 (± 0.71) than a model including age.

[Insert Figure 2 about here]

2.3. Discussion

The motion flanker task showed that overall RTs as well as the flanker effect increased as coherency level increased. Regarding age, older adults performed more slowly than younger adults but showed similar flanker costs and delta plots. Furthermore, while more inhibition appeared to be needed in the more coherent conditions, this affected younger and older adults in similar manners.

While age did not affect inhibition costs, baseline speed predicted flanker costs in different ways in younger and older adults. For younger adults, this relation was positive. Participants with faster motion perception also showed smaller costs. This could be related to overall performance: Those who performed better at a baseline task also performed better at interference suppression. However, for older adults, the relation was negative. Participants with faster motion perception showed larger flanker costs. Thus, those older participants who responded faster to motion (i.e., who performed more similar to younger adults) had larger inhibition costs. However, older adults who responded more slowly to motion in the baseline task showed smaller flanker costs. Due to slower motion perception, they may have been affected less by the motion from the flanker items. If so, the flanker items would present less interference and thus lower levels of inhibition would be needed to resolve the conflict. Processing speed, and specifically the speed with which motion is perceived and processed, may therefore affect inhibitory control. However, it is unclear whether these findings are specific to the motion flanker task or extend to other types of inhibition tasks. This was examined in Experiment 2.

3. Experiment 2

Experiment 2 firstly aimed to replicate the findings on the motion flanker task. As a second aim, we wanted to examine effects of age on inhibition across a Simon arrow (also called spatial Stroop) task, static flanker task, and motion flanker task. The Simon (arrow) and static flanker tasks have frequently been used to examine interference suppression. In the current study, the main advantage of using a Simon arrow task over a traditional Simon task concerns the similarity in stimulus materials between the Simon and static flanker task (both use arrows). Furthermore, the traditional Simon task introduces an extra memory component as participants have to remember the random connection between the stimulus´ feature and the corresponding button (e.g., left button for blue stimuli). In contrast, a Simon arrow task uses transparent rules (left button for an arrow pointing left) and as such may diminish effects of rule memorisation which may be affected by age. While the Simon arrow task introduces an additional spatial component compared to the Simon task, it should be noted that both types of the Simon task have shown age effects on inhibition costs (e.g., Castel et al., 2007; Kawai et al., 2012).

The Simon arrow, motion flanker, and static flanker tasks are similar in the sense that they present distracting information and require participants to suppress task-irrelevant information. Furthermore, all tasks use non-verbal materials. At the same time, the specific type of stimulus and type of distracting information differ between some of the tasks. While the Simon arrow and static flanker task use static stimuli (i.e., arrows), the motion flanker task uses moving stimuli. In terms of the type of interference, the Simon task differs from the two flanker tasks. In the Simon task, the distracting information (the presentation side on the screen) is part of the target itself. In contrast, in a flanker task, the distracting information is presented in the periphery. Furthermore, the type of information that needs to be suppressed is different. In the Simon arrow task, the distracting information is a spatial position while the interference in a flanker task is caused by another object with a different pointing direction. If age effects on inhibition are domain-general, they should be stable across the three tasks. However, if age effects are affected by task-specific features, different patterns may occur for each task.

Lastly, our third aim was to investigate whether the link between baseline processing speed and inhibition control is specific to moving stimuli or extends to other types of stimuli.

3.2. Methods

3.2.1. Participants

Thirty younger adults (4 male; mean age = 20.50, *SD* = 2.60, range = 18-25) and 28 older adults (5 male; mean age = 68.57, *SD* = 6.97, range = 60-86) completed Experiment 2. Two further older adults took part in the study but could not complete the motion flanker task. All participants had normal or corrected-to-normal vision and hearing, no known neurological disorders, and gave written informed consents. All participants were monolingual English native speakers and were born and raised in Scotland. In terms of years of education, there were no differences between young (*M* = 15.37, *SD* = 1.97) and older adults (*M* = 16.36, *SD* = 3.68; $t(56) = 1.26$, $p = .214$). Furthermore, the two groups did not differ significantly on the lifestyle questionnaire (Scarmeas et al., 2003; young adults: *M* = 38.27, *SD* = 3.51; older adults: *M* = 40.11, *SD* = 3.55, $t(56) = 1.98$, $p = .052$). Older participants also completed the ACE-III as a dementia screening (Hsieh et al., 2013) and all participants scored above the cut-off of 88 points (*M* = 97.79, *SD* = 2.47).

3.2.2. Materials and procedure

All participants completed three tasks: a motion flanker, static flanker, and Simon arrow task.

The motion flanker task was similar to the task described in Experiment 1. In the static flanker task, participants were presented with arrows pointing left or right and were asked to indicate the pointing direction with a button press. In the baseline condition, one arrow was presented on the centre of the screen. In the conflict condition, participants were still asked to respond to the arrow presented on the centre of the screen. However, this arrow was now surrounded by other arrows or by black squares (neutral condition). The surrounding arrows could point in the same (congruent) or opposite (incongruent) direction. To ensure comparability with the motion flanker task, flanker arrows were presented 100 ms prior to presentation of the target arrow. Arrows were presented in black on a white background and were 50 x 23 pixels. Horizontally, the five arrows were presented respectively in position (-104, -52, 0 , 52, 104). In the Simon arrow task, participants saw one arrow pointing left or right and were asked to indicate the motion direction with a button press. In the baseline condition, all arrows were presented on the centre of the screen. In the conflict condition, arrows were presented on the left or right side of the screen. This led to congruent (match between presentation side and pointing direction) and incongruent trials (mismatch between presentation side and pointing direction). The arrows were 100x46 pixels and were presented in black on a white background. Laterally presented arrows were presented 300 pixels from the centre of the screen.

The order of the three tasks was counterbalanced across participants. Each task took approximately fifteen minutes to complete and was presented in PsychoPy v 1.82 (Peirce, 2007) on a 19-inch screen with 1280x1024 resolution. Each task followed the structure baseline – conflict – baseline condition. The baseline and conflict conditions were preceded by a minimum of 12 practice trials. The two baseline blocks together consisted of 96 trials. For the Simon task, the conflict condition had four blocks with a total of 384 trials (192 congruent, 192 incongruent). The two flanker tasks had five blocks with 480 trials (96 neutral, 192 congruent, 192 incongruent). In each task, a trial started with a fixation cross on the centre of the screen for 500 ms, followed by stimulus presentation for 3000 ms or until a response was given. The complete experiment lasted approximately 60 minutes for younger adults and 75 minutes for older adults.

3.2.3. Data analysis

The data are available upon request. Again, data were analysed using both NHST and Bayesian analysis as well as through delta-plot analyses. As these tasks included more trials, we divided the RTs in five bins to allow for a better comparison of slopes across bins. To examine comparability between the three tasks, we furthermore calculated correlations between overall RTs as well as inhibition costs.

3.3. Results

3.3.1. Accuracy analysis

Accuracy scores were analysed using a binary logistic regression analysis. For the motion flanker task, there was no age effect on the baseline data ($\chi^2(1) = .16$ $p = .686$; young: M = 98.92, SD = 2.07; old: M = 99.03, SD = 1.44). In the conflict condition (see Table 2), there was a main effect of age with older adults performing more accurately than younger adults ($\chi^2(1) = 28.77$, $p < .001$). Incongruent trials were furthermore less accurate than congruent items ($\chi^2(1) = 49.95$, $p < .001$), but there was no effect of coherency ($\chi^2(3) = 2.41$ $p = .491$). The interactions did not reach significance ($p > .05$).

For the static flanker task, older adults performed more accurately than younger adults in the baseline condition ($\chi^2(1) = 45.18$, $p < .001$). In the conflict condition, incongruent items were less accurate than neutral and congruent items ($\chi^2(2) = 30.88$, $p < .001$) and older adults responded more accurately than younger adults ($\chi^2(1) = 13.31$, $p < .001$). Congruency and age did not interact ($\chi^2(2) = .82$ $p = .664$).

For the Simon arrow task, older adults performed more accurately than younger adults in the baseline condition ($\chi^2(1) = 75.84$, $p < .001$). In the conflict condition, there was a main effect of older adults being more accurate ($\chi^2(1) = 43.33$, $p < .001$) and incongruent trials being less accurate ($\chi^2(1) = 15.38$, $p < .001$). The interaction between congruency and age was not significant ($\chi^2(1) = .39$, $p = .533$).

3.3.2. RT analysis

Effects of age, coherency, and congruency

Motion flanker task.

Incorrect trials and RTs more than 2.5 *SD* above the mean (3.47% of the correct trials) were removed for the RT analysis. In the baseline condition, older adults ($M = 640.43$, $SD = 138.85$) responded more slowly than young adults ($M = 494.72$, $SD = 138.99$; $t(56) = 3.99$, $p < .001$, $\eta_p^2 = .22$, $BF_{10} = 125.67 \pm 0\%$).

For the conflict condition, we carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. There was a main effect of trial type ($F(2, 112) = 14.86$, MSE = 695.44, $p < .001$, $\eta_p^2 = .21$). While RTs were similar for congruent trials ($M = 596.33$, $SD = 138.12$) and neutral trials ($M = 581.22$, $SD = 122.62$), they were slower for incongruent trials ($M = 608.00$, $SD = 117.54$). Older adults ($M = 667.25$, $SD = 111.84$) performed more slowly than younger adults overall ($M = 532.68$, $SD = 99.30$; $F(1, 56) = 24.13$, MSE = 33117.09, $p < .001$, $\eta_p^2 = .30$). The interaction between age and trial type was not significant ($F(2, 112) = .36$, MSE = 695.44, $p = .696$, $\eta_p^2 = .01$). This suggests that flanker effects did not differ between age groups (see Table 2) as was also confirmed by the Bayesian analysis comparing the model with interaction age x trial type to the model with main effects only. The model without an interaction fits the data better by a factor of 7.76 (± 6.43%).

We then examined the effects of coherency level by only including congruent and incongruent trials in a three-way repeated ANOVA with trial type (congruent, incongruent) and coherency level (40%, 60%, 80%, 100%) as within-subject factors and age group (young, old) as a between-subject factor. Similar to the previous analysis, the main effects of congruency ($F(1, 56) = 4.31$, MSE = 3515.63, $p = .042$, $\eta_p^2 = .07$) and age ($F(1, 56) = 22.21$, MSE = 93648.57, $p < .001$, $\eta_p^2 = .28$) reached significance. Contrary to the results of Experiment 1, the effect of coherency ($F(3, 168) = 1.10$, MSE = 535.51, $p = .350$, $\eta_p^2 = .02$) and the interaction between coherency and congruency ($F(3, 168) = .77$, MSE = 463.26, $p = .511$, $\eta_p^2 = .01$) did not reach significance (see Table 2). There was no interaction between age and congruency ($F(1, 56) = .33$, MSE = 3515.63, $p = .567$, $\eta_p^2 = .01$), age and coherency ($F(3, 168) = 1.60$, MSE = 535.51, $p = .192$, $\eta_p^2 = .03$), nor a three-way interaction ($F(3, 168) = 1.33$, MSE = 463.26, $p = .266$, $\eta_p^2 = .02$), suggesting that inhibition costs were similar for the two age groups. The Bayesian analysis showed that a model without an interaction between age and congruency was preferred compared to a model with this interaction by a factor of 3.81 (± 1.35%).

Again, we calculated proportional inhibition costs for the 100% coherent condition and examined effects of age. There was no significant effect of age ($t(56) = 1.34$, $p = .186$; BF_{10} = .56 ± 0%).

Static flanker task.

For the reaction time analysis, we removed all incorrect trials as well as RTs more than 2.5 *SD* above the mean (2.02% of the correct trials). The baseline condition showed that older adults (*M* = 548.29; *SD* = 84.62) responded more slowly than young adults (*M* = 408.66, *SD* = 62.83; $t(56) = 7.10$, $p < .001$, $\eta_p^2 = .48$, BF_{10} = 3480590 ± 0%).

For the conflict condition, we carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. RTs were fastest for congruent trials (*M* = 488.46, *SD* = 99.61), followed by neutral trials (*M* = 506.18, *SD* = 97.43), and incongruent trials (*M* = 551.47, *SD* = 95.58; $F(2, 112) = 168.41$, MSE = 362.39, $p < .001$, $\eta_p^2 = .75$) and older adults (*M* = 590.40, *SD* = 83.43) performed more slowly than younger adults overall (*M* = 448.38, *SD* = 41.53; $F(1, 56) = 70.56$, MSE = 12533.20, $p < .001$, $\eta_p^2 = .56$). The interaction between age and trial type was not significant ($F(2, 112) = .59$, MSE = 362.39, $p = .555$, $\eta_p^2 = .01$). This suggests that flanker effects did not differ between age groups (see Table 2). This was confirmed by the Bayesian analysis comparing the model with interaction age x trial type to the model with main effects only. The model without an interaction fits the data better by a factor of 3.62 (± 1.05%).

Proportional inhibition costs were calculated next to correct for age-related differences in processing speed. This yielded a significant effect of ageing on proportional inhibition costs ($t(56) = 2.29$, $p = .026$, $\eta^2 = .09$; $BF_{10} = 2.27 \pm 0\%$). However, this difference went in the opposite direction: Younger adults had larger proportional inhibition costs than older adults.

Simon arrow task.

For the reaction time analysis, we removed all incorrect trials as well as RTs more than 2.5 *SD* above the mean (2.50% of the correct trials). The baseline condition showed an effect of age group ($t(56) = 8.09$, $p < .001$, $\eta^2 = .54$; $BF_{10} = 118644827 \pm 0\%$), with older adults ($M = 532.71$, $SD = 76.86$) being slower than younger adults ($M = 393.45$, $SD = 52.88$).

To examine effects of age on inhibition, we analysed the conflict condition and carried out a two-way repeated ANOVA with trial type (congruent, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. RTs were faster for congruent ($M = 568.81$, $SD = 107.08$) than for incongruent trials ($M = 601.47$, $SD = 126.08$; $F(1, 56) = 74.73$, $MSE = 428.26$, $p < .001$, $\eta_p^2 = .57$) and older adults ($M = 673.79$, $SD = 94.72$) performed more slowly than younger adults overall ($M = 501.58$, $SD = 55.53$; $F(1, 56) = 72.43$, $MSE = 11892.05$, $p < .001$, $\eta_p^2 = .56$). The interaction between age and trial type was also significant ($F(1, 56) = 19.38$, $MSE = 428.26$, $p < .001$, $\eta_p^2 = .26$), suggesting that older adults had larger inhibition costs than younger adults (see Table 2). This was confirmed by the Bayesian analysis. Comparing the model with the interaction age x trial type to the model with the main effects age and trial type only, showed that the model with the interaction fits the data better by a factor of 274.85 (± 1.48%).

To correct for age-related slowing, we then calculated proportional inhibition costs. The effect of ageing on inhibition costs remained present ($t(56) = 3.60$, $p = .001$, $\eta^2 = .19$; $BF_{10} = 43.12 \pm 0\%$).

[Insert Table 2 about here]

[Insert Figure 3 about here]

Thus, ageing affected inhibition costs on the Simon task but not on the two flanker costs (Figure 3). To ensure that this interaction indeed differed per task, we ran an additional ANOVA with task (Simon, static flanker, motion flanker) as a within-subject variable, age (young, old) as a between-subject variable, and Simon/flanker cost as the dependent variable. For the motion flanker task, we only included the 100% flanker cost to increase comparability between tasks. There was no main effect of age $F(1, 56) = .57$, MSE = 1860.14, $p = .455$, $\eta_p^2 = .01$) on inhibition costs but there was a main effect of task ($F(2, 112) = 19.76$, MSE = 1849.28, $p < .001$, $\eta_p^2 = .26$)[3]. Post-hoc analyses showed that the static flanker task had larger flanker costs than the Simon and motion flanker task (respectively $p = .001$, $p < .001$). The Simon and motion flanker task did not differ significantly ($p = .058$). Furthermore, there was a significant interaction between age and task ($F(2, 112) = 5.29$, MSE = 1849.28, $p = .006$, $\eta_p^2 = .09$), confirming that the effects of ageing on inhibition were different for the three tasks. This was also confirmed by the Bayesian analysis. The model including main effects of age and task as well as an interaction between task and age scored best and was preferred by a factor of 12.07 (± 2.23) over a model without an interaction between task and age.

Effects of baseline RTs on inhibition costs

For each task, we also ran a regression analysis with the inhibition cost as the dependent variable and age (young, old) and RTs from the baseline condition as the predictors. To ensure comparability between tasks, we only used the 100% motion flanker cost (see Table 2).

For the motion flanker task, an interaction between baseline and age ($b = -.29$, $t = -3.11$, $p = .003$) was found. Again, we ran the analysis separately for the two age groups. For the younger adults, baseline RT was not a significant predictor of flanker costs ($b = -.10$, $t = -1.98$, $p = .058$, $BF_{10} = 1.44 \pm 0$). For older adults, baseline RT was a significant and negative predictor of flanker costs ($b = -.39$, $t = -4.79$, $p < .001$, $BF_{10} = 324.66 \pm 0$). Thus, similar to

[3] It should be noted that a comparison of the raw inhibition costs of the Simon and flanker tasks is hindered by the presentation of distracting information preceding the onset of the target in the two flanker tasks. Due to the nature of the Simon arrow task, distracting information is presented at the same time as the target information. This may affect the size of the inhibition cost (cf., Burle, van den Wildenberg, & Ridderinkhof, 2005).

Experiment 1, older adults with slower baseline speed processing showed smaller flanker costs.

For the static flanker task, there was no main effect of baseline (b = -.01, t = -.12, p = .909, BF_{10} = .50 ± 0) nor an interaction with age (b = -.10, t = -.90, p = .373), suggesting that flanker costs and processing speed were unrelated for both age groups.

For the Simon task, a main effect of baseline (b = .14, t = 6.00, p < .001) was found that did not interact with age (b < .01, t = .24, p = .812). This suggests that for both younger and older adults, faster baseline processing speed was related to smaller Simon costs. The Bayes factor provided strong evidence for an effect of baseline RT (BF_{10} = 72969.17 ± 0)

3.3.3. Delta-plot analysis

Motion flanker task

The motion flanker task firstly showed a significant effect of bin ($F(3, 168)$ = 7.49, MSE = .08, p < .001, η_p^2 = .12), with inhibition costs decreasing with slower responses. Slopes were also more negative for the higher coherency level ($F(1, 56)$ = 8.45, MSE = .09, p = .005, η_p^2 = .13). Furthermore, there was a main effect of age ($F(1, 56)$ = 13.01, MSE = .19, p = .001, η_p^2 = .19, see Figure 4) with more negative slopes for older than younger adults. None of the interactions were significant (ps < .05). The Bayesian analysis showed that the model with age and bin as main effects fits the data better by a factor of 26.67 (± .44) than a model excluding age.

Static flanker task

On the static flanker task too, there was a significant effect of bin ($F(3, 168)$ = 3.68, MSE = .06, p = .013, η_p^2 = .06). The slopes, however, did not differ between age groups ($F(1, 56)$ = .57, MSE = .15, p = .456, η_p^2 = .01; see Figure 4) and age did not interact with bin ($F(3, 168)$ = .28, MSE = .06, p = .837, η_p^2 = .01). The model with bin as the only main factor explained the data better by a factor of 3.62 (± .3) compared to a model with bin and age as the main factors.

Simon arrow task

On the Simon arrow task, there was a significant effect of bin ($F(3, 168)$ = 3.66, MSE = .05 p = .014, η_p^2 = .06). Furthermore, the slopes were steeper for younger than older adults. While inhibition costs decreased with slower responses in young adults, the costs remained similar across response times for older adults (Figure 4). However, the *p* value for age did not reach significance ($F(1, 56) = 3.98$, MSE = .12, $p = .051$, $\eta_p^2 = .07$). Age did not interact with bin ($F(3, 168) = .70$, MSE = .04, $p = .551$, $\eta_p^2 = .01$). Although the model including age and bin as main factors was the best model in the Bayesian analysis, the model including age was only 1.20 times (± .29) better than a model without age.

[Insert Figure 4 about here]

3.3.4. Correlations between the three tasks

The overall RTs were all highly correlated between the three tasks (Simon & static flanker: $r = .88$, $p < .001$; Simon & motion flanker: $r = .77$, $p < .001$; static flanker & motion flanker: $r = .74$, $p < .001$). None of the inhibition costs correlated significantly between the three tasks (Simon & static flanker: $r = .14$, $p = .313$; Simon & 100% motion flanker: $r = -.17$, $p = .192$; static flanker & 100% motion flanker: $r = .25$, $p = .062$).

3.4. Discussion

Similar to Experiment 1, the motion flanker task showed a main effect of age and congruency, but no interaction between the two. However, flanker costs did not significantly increase with coherency in this experiment.

As a second aim, we compared effects of age on inhibition across three tasks. All tasks showed that older adults performed more slowly than younger adults. On the static flanker and motion flanker task, there was no difference in flanker costs between younger and older adults. Yet, on the Simon arrow task, older adults did show larger inhibition costs than younger adults. This suggests that ageing may affect inhibition differently depending on the task. This was confirmed by the delta-plot analysis. On the Simon arrow task, younger adults showed negative slopes while older adults showed positive slopes (see e.g., Juncos-Rabadán et al., 2008, for similar results). This is compatible with the interpretation that younger adults were more successful at inhibiting the irrelevant information than older adults. Furthermore, the delta plots suggested that there were further differences between the static flanker and motion flanker task despite both tasks not showing a negative effect of age on inhibition costs.

In the static flanker tasks, slopes were similar for older and younger adults, suggesting that their inhibitory performance was comparable. However, in the motion flanker task, slopes were more negative for older than younger adults.

The effects of baseline speed on inhibition costs showed different findings for the three tasks. For the Simon task, both younger and older adults with faster baseline processing speed showed smaller inhibition costs. This is compatible with the type of inhibition present in this task. Participants have to respond to one arrow only and are distracted by the presentation side of the screen. Thus, those perceiving the arrow's pointing direction faster may also have less interference from the presentation side. On the static flanker task, there was no effect of baseline processing speed on inhibition costs. However, on the motion flanker task, we again observed a negative relation between motion perception and inhibition costs for older adults but not younger adults. Older adults who perceived motion faster also showed larger inhibition costs, possibly because they were more affected by interference from the flanker dots.

4. General Discussion

Across two experiments, younger and older adults completed three inhibition tasks: a Simon arrow, static flanker, and motion flanker task. Although these three tasks can all be argued to measure interference suppression, they have different task-specific features. While all tasks showed effects of congruency and slower RTs for older than younger adults, effects of age on inhibition costs were only found in the Simon arrow task. Furthermore, the motion, but not static flanker task, showed a relation between baseline processing speed and inhibition costs in older adults. Slower stimulus perception may lead to lower interference and consequently to smaller inhibition costs.

4.1. What are the effects of age on inhibition?

On the Simon arrow task, older adults showed larger inhibition costs than younger adults, even when proportional Simon costs were analysed to correct for baseline difference. These findings are compatible both with previous studies using Simon tasks (e.g., Castel et al., 2007; Proctor et al., 2005) as well as with previous work on Simon arrow tasks (e.g., Kawai et al., 2012). The delta-plot analyses furthermore showed decreasing Simon effects with longer RTs for younger but not older adults. Castel et al. (2007), who observed similar age effects on RT distributions, suggested that while younger adults use more controlled processing at longer RTs, older adults do not.

On the two flanker tasks, we did not observe effects of age on inhibition costs. When proportional costs were analysed, the static flanker task even showed smaller costs for older adults (see also Hsieh et al., 2012; Jennings et al., 2007). Although the literature suggests that different patterns of ageing may arise on Simon versus flanker tasks, not many studies have directly compared the two. An exception is the study by Kawai et al. (2012), who also tested older adults on a Simon arrow and static flanker task. Similar to our study, effects of ageing were only found on the Simon but not the flanker task. This different pattern could be related to the type of inhibition in the Simon versus flanker task. In the Simon task, the irrelevant information is part of the stimulus itself and thus highly salient. In the flanker task, however, the irrelevant information is not part of the stimulus, but presented next to the target. Wild-Wall et al. (2008) suggested that older adults focus more on the target stimulus and are less affected by the congruency of the surrounding information. This may explain why older adults show similar or even smaller (proportional) inhibition costs than younger adults on flanker tasks. Furthermore, peripheral vision generally declines with age (e.g., Johnson, Adams, & Lewis, 1989). Although our older participants all had normal or corrected-to-normal vision and did not report any vision problems, they may be less affected by peripheral information than younger adults. However, in the Simon arrow task, older adults will not benefit from enhanced target processing and decreased interference from flanker items as interference is part of the target itself.

Apart from the location of the interference (part of the stimulus vs. in the periphery), the type of interfering information also differed between tasks. On the Simon arrow task, spatial information needs to be suppressed. On the flanker tasks, the identity of an object needs to be suppressed. Our results are compatible with previous findings suggesting that age effects differ between inhibition of spatial information versus object identity (e.g., Connelly & Hasher, 1993; McCrae & Abrams, 2001). Connelly and Hasher (1993) applied a negative priming paradigm with either location or identity distractors. Targets shown in a location previously occupied by a distractor were processed more slowly than targets in previously unoccupied locations. This effect was similar for younger and older adults, suggesting that both age groups inhibited the object´s location. In contrast, when the identity of an object had to be suppressed, these effects were only found for younger but not older adults. This suggests that older adults may have impoverished inhibitory control for object identity but not for spatial locations. Based on these findings, one would expect older adults to show larger inhibition costs on a flanker task (where the object´s identity needs to be suppressed) than on a Simon arrow task (where the object´s location needs to be suppressed). Yet, our results (as well as those reported by Kawai et al., 2012) apparently go in the opposite direction: Age effects were larger on tasks requiring location than identity inhibition. These apparently contradictory results can be reconciled if the perceptual level of conflict is taken into account. If older adults have unimpaired location processing, this will require inhibition of the distractor´s location on a negative priming task and this will lead to costs similar to the younger adults on the next trial. Similarly, in a Simon arrow task, location will be processed rapidly enough by both older and younger adults to cause interference at the perceptual level. However, older adults take longer to resolve this interference and as such show larger Simon costs. In contrast, if an object´s identity is processed less quickly by older adults, the distractor´s identity would cause less interference for older adults on both negative priming and flanker paradigms and as such inhibition costs should respectively be larger for younger adults or equal. However, this explanation is speculative and the role of processing speed and possible differences between object identity and spatial locations need to be studied in more detail.

Assessing the delta-plot analyses more generally shows some inconsistencies with previous studies. The Simon arrow task, consistently with previous Simon tasks, generally shows negative slopes (cf., Ridderinkhof et al., 2004). The flanker tasks too show either flat or negative slopes in the current studies while previous studies have observed increasing slopes for flanker tasks (cf., Burle, Spieser, Servant, & Hasbroucq, 2014). This slope was particularly steep in the slowest RT bin in the group of older adults in the motion flanker task, leading to reversed inhibition costs (suggesting faster performance to incongruent rather than congruent trials). This may mean that when older adults use relatively much time to take a decision on the motion flanker task, they may over-apply inhibition. However, the group of younger adults too, showed reversed inhibition costs for the slowest motion flanker RTs in the delta-plot analysis. While the difference in inhibition costs may have been numerically smaller for younger adults in the slowest RT, age effects did not show a significant interaction with bin. Furthermore, the reversal of inhibition costs was only observed on the motion flanker but not the static flanker task[4]. Thus, this particularly steep slope for the slowest RTs in the delta-plot analysis for the motion flanker task may be yet another example of task-related differences.

4.2. Baseline processing speed and inhibition

As a second question, we examined effects of baseline processing speed on inhibition costs for both age groups. Again, we observed different patterns for the three tasks. The Simon arrow task showed, for both age groups, that faster baseline processing speed relates to smaller inhibition costs. Those who responded more quickly to the pointing direction of the arrow were also affected less by the interference. For the static flanker task, no effects of baseline speed on inhibition costs were found for either age group. The motion flanker task showed different patterns for younger and older adults in both experiments. Older adults who responded faster to baseline motion showed larger inhibition costs, possibly because they had more interference from the motion flankers. This supports previous studies (e.g., Hsieh et al., 2012; Van´t Ent, 2002) that proposed that the perceptual conflict arising between flanker stimuli and the target stimulus is the underlying source of flanker interference costs. These findings are also compatible with the interpretation by Wild-Wall et al. (2008) regarding the automaticity of information transfer from visual to motor areas. If baseline information is processed faster, this could lead to increased interference from flanker items. On the other hand, if baseline information is processed more slowly, the delayed transmission may also cause less interference and thus older adults with slower motion processing show smaller flanker costs.

While the motion flanker task showed effects of processing speed, the static task did not. We used a motion flanker task as motion perception generally deteriorates with age (e.g., Tran et al., 1998). For both flanker tasks, older participants performed more slowly than younger adults in the baseline condition with the difference between the young and older adults being similar for the two tasks. Yet, the standard deviations are larger on the motion

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[4] Negative inhibition effects have been suggested to be linked to cues or distracting information preceding the target (Burle et al., 2005). However, in both flanker tasks, presentation of flankers preceded the target while negative inhibition costs were only observed on the motion flanker task.

task, suggesting that performance is more heterogeneous. Due to this variability, effects may have been more likely to occur on the motion than static flanker task.

A remaining question is whether possible effects of stimulus perception and processing speed are specific to older adults or could occur for younger adults too. In the current sample, all younger adults reported good vision and showed no problems in the motion perception task. However, it could be argued that when younger adults with good and poor motion perception are compared, similar results should arise as for the older adults.

4.3. Task comparability

Inhibition costs across tasks sometimes correlate poorly (e.g., Paap & Greenberg, 2013). We observed a similar pattern. While overall RTs correlated highly between the three tasks, the inhibition costs did not correlate significantly. Firstly, it should also be noted that difference scores have been argued to show lower reliability, which could lead to lower correlations (cf., Friedman & Miyake, 2004, for a discussion). Additionally, the low correlations between the Simon and flanker tasks highlight the issue of task impurity. Inhibition tasks not only measure the component that we aim to measure (i.e., inhibition), but are also largely affected by other components such as processing speed and task-specific features. Given the differences between tasks, differential effects of ageing on inhibition can be expected and were indeed observed in this study.

4.4. Do we need inhibition to explain age effects on ´inhibition tasks´?

The results of the current study suggest that older adults may show inhibition deficits on some task paradigms (such as the Simon arrow task). On other paradigms, however, age effects on inhibitory control tasks may be modified by factors other than the ability to inhibit information (such as baseline processing speed).

Additionally, through the use of drift-diffusion models, it has been suggested that older adults use a more cautious approach on inhibition tasks than younger adults. If so, one would expect overall RTs to be slower in combination with higher accuracy for older adults (Ratcliff, Thapar, Gomez, & McKoon, 2004; Schuch, 2016). Indeed, older adults in our study not only performed more slowly but also more accurately than younger adults in all tasks apart from the motion flanker task in Experiment 1. Thus, in addition to changes in inhibitory control and baseline processing speed, strategic differences may also play a role in the outcome of interference tasks. At the same time, this pattern of higher accuracy was observed in the baseline condition of the Simon arrow and flanker task too. This suggests that older adults may have been more cautious overall than younger adults but not specifically in response to conflict. Furthermore, the same accuracy pattern (higher accuracy for older adults on both the baseline and conflict task) was observed for the Simon arrow as well as the static flanker task despite differential age effects on the inhibition cost. Thus, while strategic differences and the cautiousness with which responses are given may play a role in ageing studies, they cannot explain the differential age patterns on inhibition costs in this study.

While the above discussion is based on the assumption that inhibition is used in the Simon and flanker tasks, it should be noted that some studies have suggested that inhibitory control is not necessary in interference tasks (e.g., Egner & Hirsch, 2005). Rather, these tasks may be performed through enhancing the response to relevant information instead of through inhibition of irrelevant information. This is compatible with Wild-Wall´s suggestion that older adults were not only affected less by flankers, but also focussed more on the target. Thus, apart from inhibitory control differences and processing speed, strategic differences and increased attention to task-relevant information could further modify performance on interference suppression tasks and the relation with age.

5. Conclusion

In conclusion, our study suggests that the effects of age on inhibitory control depend on task-specific features. An effect of age on inhibition occurred on the Simon but not the flanker tasks. Consistent with Hasher & Zacks (1988), we found that older adults may have impoverished inhibitory control, even when corrected for age-related slowing. However, the manifestation of age effects on inhibitory control depends on the task paradigm and the type of interference that is presented. The relationship with processing speed in the motion flanker task furthermore suggested that age effects may depend on the speed with which stimuli are processed. Effects of age on inhibition can thus depend on the type of task-irrelevant information, the type of stimulus materials, processing speed, as well as the interactions between these components.

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Disclosure of interest

The authors report no conflicts of interest.

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